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Technical Report

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This report in response to the renewed interest in control of evaporative emissions at high altitude, discusses the difference in non-controlled evaporative emissions between locations near sea-level and those in high altitude areas. Determination of this difference in emissions will result in the identification of control standards for high altitude which given similar percent reductions as standards in effect for low altitude areas. Mathematical models developed for the prediction of evaporative losses are described.

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Effect of Altitude on Non-Controlled Evaporative Emissions
from Gasoline-Fueled Vehicles

I. Introduction

With the renewed interest in control of evaporative emissions at high altitude, it has become necessary to establish the difference in non-controlled evaporative emissions between locations near sea level and locations in high altitude areas. Determination of this difference in emissions will result in the identification of control standards for high altitude which given similar percent reductions as standards in effect for low altitude areas.

II. Discussion

There is very little published test data which compares evaporative emissions at different altitudes. However, there has been considerable testing done for the effect of fuel volatility on evaporative emissions. There have also been mathematical models developed for the prediction of evaporative losses. These models generally have a theoretical basis and have been shown to agree with experimental data gathered under low altitude conditions. It appears that these models are applicable to prediction of evaporative losses at different altitudes.

A. Diurnal Loss

For the diurnal test conditions, the following equation derived by Wade[1] is applicable for prediction of non-controlled fuel tank losses:

$$G = \frac{454\ M}{C_g\ R} \left[\frac{\bar{p}}{P_a - \bar{p}}\right] \left[\left\{\frac{(P_t - p)\ V}{T}\right\}_1 - \left\{\frac{(P_t - p)\ V}{T}\right\}_2\right]$$

where:

G = Weight of fuel lost, g

M = Molecular weight of fuel vapor $\frac{\text{lb}}{\text{lb mole}}$

V = Volume of tank vapor space, ft^3

T = Temperature, °R

P_a = Atmospheric pressure, psia

P_t = Fuel tank pressure, psia

p = Partial pressure of fuel, psia

$\bar{p} = (p_1 + p_2)/2$

1 = Initial state

2 = Final state

R = Ideal gas constant = 10.73 $\frac{\text{psi ft}^3}{^\circ\text{R lb-mole}}$

C_g = Compressibility factor.

The compressibility factor (C_g) value can be obtained from the following two equations contained in an API publication[2]:

$$Z = \frac{(379.5)\ W\ C_g}{M} \quad \left(\frac{14.7}{P_v}\right)$$

and also,

$$Z = \frac{690 - 4M}{P_v}$$

where Z = Volume of saturated vapor at 60°F and 14.7 psia per gallon of liquid, ft^3

W = Weight of 1 gallon of liquid, pounds

P_v = Partial pressure of the hydrocarbon in vapor at saturation, psia.

Combining the two above expressions for Z gives

$$C_g = \frac{(690-4M)\ M}{14.7\ (379.5\ W)}$$

Substituting this into Wade's equation gives the following expression from which diurnal losses can be calculated:

$$G = 454W \left(\frac{520}{690-4M}\right) \left[\frac{\bar{p}}{P_a - \bar{p}}\right] \left[\left\{\frac{(P_t - p)\ V}{T}\right\}_1 - \left\{\frac{(P_t - p)\ V}{T}\right\}_2\right]$$

This equation has been used to calculate the amount of non-controlled fuel tank diurnal losses at sea level and at 5200 feet elevation, using Indolene fuel and the following values:

$M = 62 \frac{lb}{lb\ mole}$

$V = 1.60\ ft^3$ (Fuel tank volume = 20 gallons)
$P_a = 14.7$ psia at sea level
$= 12.2$ psia at 5200 feet
$P_t = P_a$
$P_1 = 4.6$ psia, $P_2 = 7.2$ psia

The results are listed in Table I. As shown, the calculated loss at sea level is 20.0 grams and at 5200 feet is 27.0 grams.

B. Hot-soak Loss

In regard to carburetor hot-soak losses, Wade[1] has shown that the fuel boiling process can be closely approximated by a single plate equilibrium distillation process, and the amount of fuel loss correlated well with this distillation curve at the peak carburetor temperature. On this basis, an equation has been proposed for the prediction of carburetor hot-soak losses.[3] However, since single-plate distillation data are not commonly available on gasolines, this equation can not normally be used.

A more practical solution has been the development of empirical relationships between non-controlled carburetor losses and the ASTM distillation results at the peak carburetor bowl temperature. Such relationships can be used to predict the effect of altitude on carburetor hot-soak losses since altitude has a known effect on the ASTM distillation temperatures.[4] The following empirical relationship[5] has been used to predict the effect of altitude on non-controlled carburetor hot-soak emissions:

$$G = \frac{BW}{100} (a\ V_t - b)$$

where:
G = Mass of fuel lost, g
B = Volume of fuel in bowl, cc
W = Density of fuel, g/cc
V_t = Volume % distilled at peak bowl temperature
a = Constant = 0.801
b = Constant = 4.38.

Assumed values used were:

B = 100 cc
W = 0.74 g/cc
Peak gasoline temperature in carburetor bowl = 165°F
From inspection distillation data on Indolene fuel,
V_t = 22% at sea level
= 25.5% at 5200 ft.

TABLE I

Estimated Difference in Non-Controlled Evaporative Emission Test Results Between Sea Level and an Altitude of 5200 Feet

	Sea Level	5200 Feet	% Increase
Diurnal Loss, g	20.0	27.0	35
Hot Soak Loss, g	9.8	11.9	21
Diurnal and Hot Soak, g	29.8	38.9	31

The results are listed in Table I. As shown the estimated hot-soak losses at sea level and 5200 ft. are 9.8 g and 11.9 g, respectively.

C. Summary

Table I shows the calculated difference in evaporative emission test levels between sea level and a representative high altitude location (5200 feet). The sea level and high altitude values (combining both diurnal and hot-soak losses) are 29.8 g and 38.9 g, respectively, an increase of 31% when going from sea level to 5200 feet.

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5. W. J. Koehl, Jr., "Mathematical Models for Prediction of Fuel Tank and Carburetor Evaporative Losses", SAE paper 690506, May, 1969.